

REVIEW

The role of stretching in tendon injuries

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Br J Sports Med 2007;**41**:224–226. doi: 10.1136/bjsm.2006.034165

The function of tendons can be classified into two categories: tensile force transmission, and storage and release of elastic energy during locomotion. The action of tendons in storing and releasing energy is mainly seen in sports activities with stretch-shortening cycles (SSCs). The more intense the SSC movements are (jumping-like activities), the more frequently tendon problems are observed. High SSC movements impose high loads on tendons. Consequently, tendons that frequently deal with high SSC motion require a high energy-absorbing capacity to store and release this large amount of elastic energy. As the elasticity of tendon structures is a leading factor in the amount of stored energy, prevention and rehabilitation programmes for tendon injuries should focus on increasing this tendon elasticity in athletes performing high SSC movements. Recently, it has been shown that ballistic stretching can significantly increase tendon elasticity. These findings have important clinical implications for treatment and prevention of tendon injuries.

performance is enhanced during the concentric phase. Many previous studies have shown that this phenomenon is the result of energy stored by the elastic component of the muscle–tendon unit. Anatomically, the elastic component is composed of tendinous tissue (tendon and aponeurosis); epimysium, perimysium and endomysium; sarcolemma; and endosarcomeric structures.⁷ Among these, the tendinous tissues have been shown to act as a primary elastic component.⁷ Consequently, the tendinous tissue can store mechanical work as elastic energy during eccentric contractions. The storage and subsequent release of elastic energy during stretch-shortening cycles (SSCs) have generally been considered as an “energy-saving” system.

As the tendon structures have been assumed to be the major source of elastic component, the elasticity of tendon structures is a leading factor in the amount of stored energy.

As the role of tendons differs depending on the type of activities performed, its characteristics may also be different. Activities such as cycling, boxing, skating or swimming use predominantly positive work-loops, and little opportunity exists for absorbing amounts of energy during these activities. A rather stiff tendon seems appropriate for this task, since not too much energy from the muscle contraction is wasted by the elasticity of the tendon. The stiffer the tendon, the faster the force is transferred to the bones, and the more efficient the concentric contraction becomes. In this way, the metabolic energy of the muscle is converted rather efficiently into mechanical work.

By contrast, in sports with SSC movements, a more compliant muscle–tendon unit may be required for the storage and release of elastic energy. A muscle–tendon unit involved in sports with high SSC movements needs a high storage capacity for potential energy and must, therefore, be sufficiently compliant. Wilson *et al*⁸ have shown that when the mechanical properties of the unit are optimised, maximal performance is obtained.

The use of stretching exercises to improve the flexibility is a widespread practice among competitive and recreational athletes. Numerous stretching studies have documented increases in the joint range of motion after stretching exercises.^{1–4} In addition, many studies have been performed to investigate the effectiveness of different stretching techniques to increase the joint range of motion. Although these studies contain valuable information, the aims and conclusions of these studies are almost always limited to the effect of stretching on muscle tissue. Only a few studies have examined the influence of stretching on tendons.

Before looking at the available literature on the relationship between stretching and tendons, it seems important to describe how the muscle–tendon unit works during movement and what the role of stretching on tendons might be.

THE ROLE OF THE MUSCLE–TENDON UNIT DURING DIFFERENT SPORTS ACTIVITIES

The role of muscle–tendon units may differ depending on the type of activity. Muscle–tendon units may generate forces in two distinctly different ways: (1) as an elastic-like spring in stretch-shortening motion⁵ that occurs, for example, during jumping-type activities; and (2) as converters of metabolic energy into mechanical work in predominantly concentric contractions,⁶ such as cycling or swimming. In the former role, an eccentric muscle action is immediately followed by a concentric action. It is well known that if an activated muscle is stretched before shortening, its

RELATIONSHIP BETWEEN TYPE OF SPORTS ACTIVITY AND TENDON INJURIES

Tendinopathy and tendon ruptures occur in almost every sport. However, looking at the relative incidences (absolute incidence divided by hours of sports participation), tendon injuries are significantly more frequent in sports with SSC movements.^{9–14} In addition, one can say that the more intense the SSC movements are in a certain sport, the higher the incidence of tendon problems.

Abbreviations: SSC, stretch-shortening cycle

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Accepted
14 December 2006
Published Online First
26 January 2007

Therefore, from a prevention point of view, as well as from a curative point of view, our focus should be on the sports with a substantial amount of (high) SSC movements.

In these sports with (high) SSC movements, a compliant tendon will have a higher ability to absorb energy. In the case of a high-intensity SSC movement (when a large amount of energy needs to be absorbed), the greater energy-absorbing capacity of the compliant tendon will theoretically lead to a lower injury risk in the tendon and the muscle (compared to a stiffer tendon): (1) since the compliant tendon is able to absorb more energy, the high stresses on the tendon (typically coming from the high SSC movements) will less likely reach the maximal energy-absorbing capacity of the compliant tendon, and thus will less likely lead to injury of the tendon; (2) since the compliant tendon is able to absorb more energy, little energy is transferred to the contractile apparatus, therefore reducing the risk of injury of the muscle.¹⁵

Therefore, it seems only logical from a medical point of view to ascertain that athletes involved in (high) SSC sports should have compliant tendons.

However, can we, by any means, influence the compliance of tendons, and if so what are the most appropriate characteristics?

RELATIONSHIP BETWEEN STRETCHING AND ELASTICITY OF TENDONS

Previous findings obtained from animal studies have shown that the elasticity of tendons is changeable through stretching.¹⁶

Already in 1989, Toft *et al*¹⁷ found a 36% decrease in the passive tension of human plantar flexors after a 3-week stretching programme. Further, Wilson *et al*,³ who applied a damped oscillation technique to determine the stiffness of the upper limbs, showed that the rebound bench-press performance enhancement observed consequent to flexibility training was caused by a reduction in stiffness of muscle-tendon units, increasing the utilisation of elastic energy during the rebound bench-press lift. Concordant with these two studies, Magnusson *et al*¹⁸ showed that repetitive stretches made hamstrings more compliant.

Taken together, these results indicate that stretching changes the viscoelastic properties of muscle-tendon units.

However, since in these studies the compliance of the whole muscle-tendon unit is measured (by measuring the passive resistive torque associated with the range of motion changes), from these findings it cannot be concluded whether stretching influences the stretch tolerance, and the compliance of the muscle, the compliance of the tendon, or both.

Recently, dynamometer measurements, combined with ultrasonography,^{19–23} have allowed the appreciation of stretch within human tendon structures. To date, only two studies have used these techniques to examine the effects of stretching on tendon stiffness. In the first study, Kubo *et al*²¹ investigated the effect of a 3-week static stretching programme on the triceps surae muscle.

In accordance with the findings of the previous studies, they observed a significant decrease in the passive torque values of the stretched muscle-tendon unit (in the previous studies described as an increase of compliance of the muscle-tendon unit). However, looking at the stiffness of the Achilles tendon, no significant change was observed.

Recently, we investigated the effect of a 6-week static and ballistic stretching programme on the passive resistive torque and on the stiffness of the Achilles tendon.²⁴ The results of the study revealed that static stretching resulted in a significant decrease in the passive resistive torque, without a change in Achilles tendon stiffness. By contrast, ballistic stretching resulted in a significant decrease in stiffness of the Achilles tendon.

These findings provide evidence that static and ballistic stretching have different effects on passive resistive torque and tendon stiffness. Consequently, both types of stretching could be considered as complementary for training and rehabilitation programmes.

Why these different responses of ballistic and static stretching occurred is not clear, but it may be related to the effect of stretching on the contractile elements versus the tendon. While the resting contractile elements have been shown to be more compliant than the tendon for a particular length, the much greater length of tendon attached to the plantar flexor muscles *in vivo* means that when these muscles are stretched, much greater strains are observed in the tendon than in the contractile elements.²⁵ It may be that these larger strains induce an adaptation in the collagen fibres within the tendon, and this adaptation may require a repetitive changing stimulus (applied force) such as seen in ballistic stretching as compared with the sustained steady force associated with static stretching.

Another possible mechanism that may explain the observed difference between static and ballistic stretching on tendon stiffness is related to the activation versus relaxation of the stretched muscle. Static stretching involves a slow, controlled lengthening of a relaxed muscle. By contrast, ballistic stretching causes the facilitation of the stretch reflex, which is mediated by the facilitatory influences of muscle spindles type Ia and II receptors on homonymous α motor neurone excitability.²⁶ This activation of the stretch reflex causes a contraction in the muscle being stretched. As a result, the static stretch will have a greater influence on the relaxed (and thus more compliant) muscle tissue, whereas the ballistic stretch deals with a contracted (and thus stiffer) muscle, and as a result will have a greater effect on the tendon tissue. However, further research is needed to identify the exact working mechanism of the static versus the ballistic stretch.

Several studies have shown the superior results of eccentric exercise protocols in the treatment of tendinopathy.^{27–34} Many different explanations are proposed to explain these good results.^{35–37} Performing eccentric exercises is similar to ballistic stretches. In both exercises, the muscle is contracting while the tendon is elongating and this occurs in a repetitive manner.

What is already known on this topic

- Muscle flexibility is frequently mentioned as an important factor in the prevention and rehabilitation of tendon injuries.
- Much research has been carried out with regard to the effect of different stretching techniques on the range of motion.
- On the basis of the results of these studies, some stretching techniques are found to be superior to others.

What this study adds

- This paper looks at the effects of different stretching techniques on different muscle-tendon structures.
- These findings provide evidence that static and ballistic stretching have different effects on passive resistive torque and tendon stiffness.
- Consequently, both types of stretching could be considered as complementary for the training and rehabilitation programmes of tendon injuries.

Theoretically, an eccentric exercise programme can lead to a decreased tendon stiffness (similar to the ballistic stretching programme). If so, this leads to an increased tendon energy capacity and this might be one of the explanations for the good clinical results of an eccentric exercise programme. Future research should examine tendon stiffness after an eccentric programme, and should evaluate the beneficial effect of ballistic stretching in an eccentric training programme, and in the prevention and rehabilitation of tendon injuries.

CONCLUSIONS

Sports with high SSC movements have a higher incidence of tendon injuries. Sports with high SSC movements impose high loads on tendons. In these high SSC sports, muscle-tendon units act as elastic-like springs during the SSC motions. To store and release these high loads without tendon tissue damage, tendons require a great energy-absorbing capacity. If this capacity is insufficient, the demands in energy absorption and release may rapidly exceed the tendon capacity. This may lead to an increased risk for tendon overload—for example, injury. Therefore, increasing the energy capacity of tendons must be one of the key points in the prevention and treatment of tendon injuries. Decreasing the stiffness of a tendon has been shown to increase its energy capacity.

Recently, it has been shown in humans that a static stretching programme has no influence on tendon stiffness. By contrast, a ballistic stretching programme can increase the compliance of tendons.²⁴ Therefore, findings have implications for the prevention and treatment of tendon injuries, and both ballistic and static stretching should be incorporated in the prevention and treatment programmes for tendon injuries.

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Competing interests: None declared.

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